行政院國家科學委員會專題研究計畫 成果報告

台灣地區譜震度衰減律的研究(II)
研究成果報告(精簡版)

計畫類別：整合型
計畫編號：NSC 98-2119-M-041-001-
執行期間：98年08月01日至99年07月31日
執行單位：嘉南藥理科技大學產業安全衛生與防災研究所

計畫主持人：葉永田
共同主持人：高清雲
計畫參與人員：碩士級-專任助理人員：蔡坤憲
碩士班研究生-兼任助理人員：陳昱任
碩士班研究生-兼任助理人員：李淑芬
講師級-兼任助理人員：陳達毅

報告附件：出席國際會議研究心得報告及發表論文

處理方式：本計畫可公開查詢

中華民國 99年11月03日

行政院國家科學委員會補助專題研究計畫 ■成果報告 □期中進度報告

台灣地區譜震度衰減律的研究(II)

計畫類別：□個別型計畫 ■整合型計畫
計畫編號：NSC 98－2119－M－041－001－
執行期間：98 年 08 月 01 日至 99 年 07 月 31 日

執行機構及系所：嘉南藥理科技大學產業安全衛生與防災研究所

計畫主持人：葉永田
共同主持人：高清雲
計畫參與人員：蔡坤憲、陳昱任、陳達毅、李淑芬

成果報告類型(依經費核定清單規定繳交)：■精簡報告 □完整報告

本計畫除繳交成果報告外，另須繳交以下出國心得報告：
□赴國外出差或研習心得報告
□赴大陸地區出差或研習心得報告
■出席國際學術會議心得報告
□國際合作研究計畫國外研究報告

處理方式：除列管計畫及下列情形者外，得立即公開查詢
□涉及專利或其他智慧財產權，□一年□二年後可公開查詢

中 華 民 國 99 年 10 月 29 日

1. Abstract

Nowadays, the structural environment is becoming so complicated that the originally defined intensity scale and PGA are not adequate to do a good job for assessing earthquake damage. Therefore, an index adequately assess earthquake damage is needed. Spectrum intensity (*SI*) includes the three elements, duration time, frequency content, and amplitude, of strong ground motion affecting earthquake damage and it is a more adequate intensity parameter to assessing earthquake damage. Based on previous study, a three-parameter spectrum intensity system is re-searched in this project. The three period ranges of the proposed spectrum intensity are determined by the earthquake records collected in a certain area since the adequate period range of the *SI* belongs to regional surface geology and earthquake source characteristics. Finally, regression analysis of spectrum intensity attenuation model using genetic algorithm in southwest Taiwan was studied.

以今日複雜的結構物環境，很難再以原始定義的震度或最大地表加速度來推估可能的震災。因此，有必要發展一個有效的震災指標。譜震度組合了強地動的持續時間、頻率內涵、和振幅等三種影響震災的性質，是一個比較有效的震災指標參數。基於前人的研究基礎，本計畫再檢討三段式譜震度的周期分界。因為強地動特性是受到區域淺層地質和震源過程支配的，本研究發展出一個以特定區域蒐集到的強地動歷時記錄，推導三段式譜震度周期分界的方法。最後，我們也應用這個方法以及基因演算法推求台灣西南部地區的譜震度模式。

keywords：Spectral intensity, Attenuation law, southwest Taiwan；譜震度，震度衰減律，台灣西南部。

2. Introduction

Earthquake engineers usually use peak ground acceleration (PGA) to assess possible earthquake damage. Since PGA can only represent the earthquake force during a very short time (or maximum earthquake force) and is composed of higher vibration frequencies, PGA influences low-rise buildings with simple structure and higher natural frequency larger. Nowadays, the structural environment is becoming so complicated that the originally defined intensity scale and PGA are not adequate to do a good job for assessing earthquake damage.

The researchers of earthquake and earthquake engineering keep making effort to search for some representative intensity parameters which can reflect the scenario of earthquake disaster and then investigate their attenuation law to be a tool for earthquake disaster potential assessment. Since the earthquake duration, frequency content, and amplitude are three important elements affecting damage, more adequate intensity parameter should reflect integrated effect of the three elements. Housner[1] argued that spectrum intensity (*SI*) can be a risk index (a measure of severity) of an earthquake. The *SI* is defined as the area under the spectrum curve between the periods 0.1 and 2.5 sec,

$$SI_H = \int_{0.1}^{2.5} S_v(T,\xi)dT \tag{1}$$

where $S_v(T, \xi)$ is the pseudo-velocity for a structural model with a natural period T and damping ratio ξ. *SI* defined by Housner can also be expressed the average of $S_v(T, \xi)$ between the periods 0.1 and 2.5 sec

$$SI_H = \frac{1}{2.4}\int_{0.1}^{2.5} S_v(T,\xi)dT \tag{2}$$

SH_H can be regarded as the vibration energy of structures with natural period from 0.1 s to 2.5 s induced by an earthquake. In fact, the integral interval in Equations (1) and (2) could be too wide to deal with different types of buildings.

After Housner some earthquake engineers keep on exploring *SI* with different period range and its application [2-5]. Hidalgo and Clough [2] researched the reasonable period range of reinforced concrete building for Equation 2. The study of Matsumura [3] shows that *SI* has a good correlation with damage and it is a better measurement of earthquake intensity than peak ground acceleration (adequate to structures with shorter natural period) and peak ground velocity (adequate to structures with longer natural period) for a wide range of frequencies. Nau and Hall [4] studied the scaling methods for earthquake response spectrum using an ensemble of 12 earthquake records. They showed that a three parameter system of spectrum intensities, computed within low, medium, and high frequency regions, may provide a better means of scaling earthquake response spectra. Martinez-Rueda [5] presented a combined criterion to define *SI* by optimizing the correlation between *SI* and displacement ductility demand. Three period ranges of structure, $T_y \leq 0.6$ sec, 0.6 sec $< T \leq 1.6$ sec, and $T_y > 1.6$ sec, were adopted in his study.

Recently, some researchers investigate the relationship between *SI* and earthquake damage in Taiwan [6-7]. Jean et al. [6] proposed a concept of simplified uniform hazard response parameter and applied it to Taipei basin for the 2002-03-31 Hualien earthquake in Taiwan. Ueong [7] used a three-parameter spectrum intensity system with period ranges proposed by Martinez-Rueda [5] to study the feasibility of spectra intensity for identification of earthquake damages in Taiwan. The three period ranges are 0.1-0.6, 0.6-1.6, and 1.6-3 sec. for short period (acceleration controlled period), medium period (velocity controlled period), and long period (displacement controlled period), respectively. His study indicated that the three-parameter system is a good risk index of the damage potential of earthquakes. In fact, the reasonable period range of *SI* belongs to area and earthquake characteristics. It should be determined from the station earthquake records in a certain area. Based on this reason, a novel three-parameter spectrum intensity system is developed in this study. Finally, regression analysis of spectrum intensity attenuation model using genetic algorithm in southwest Taiwan was studied.

3. Data

The Taiwan strong-motion seismic network consists of about 700 free-field strong-motion stations. Each station includes triaxial accelerometers, a digital recorder, a power supply, and a GPS timing system. Most of the digital accelerometers used in these stations are ±2g full scale, 200 or higher samples per second, and 16-bit or better resolution with up to 20-second pre-event recording [8]. The strong-motion stations are spaced approximately 5 km apart in nine metropolitan regions. The Taiwan strong-motion seismic network has collected a large amount of high quality strong-motion data and provided much useful information for seismology and earthquake engineering. These ground motion data offer a good opportunity to study attenuation models. Earthquake data collected from Taiwan strong-motion seismic network were used in this study to develop the empirical spectrum intensity attenuation model.

The database consists of 7929 recordings collected from 578 earthquake events of local magnitude $4.0 \leq M_L \leq 7.3$ from 1993 to 2008.

4. Methodology

Spectrum Intensity

This study modified the concept proposed by Jean [6] and the average spectrum intensity is defined as follows

$$\bar{S}(\xi) = \frac{1}{T_2 - T_1} \int_{T_1}^{T_2} S(\xi, T)\, dT \tag{3}$$

where

$S(\xi, T) = S_a(\xi, T)$ (short period) acceleration controlled period (4)

$S(\xi, T) = S_v(\xi, T)$ (medium period) velocity controlled period (5)

$S(\xi, T) = S_d(\xi, T)$ (long period) displacement controlled period (6)

where S_a is the absolute acceleration spectra, S_v is the pseudo velocity spectra, and S_d is the relative displacement spectra. The period ranges, T_1 and T_2, of S_a, S_v, and S_d belong to area characteristic, they can be computed from their average value of numerous strong earthquakes in the research area. The method in this study of computing T_1 and T_2 is shown in Figure 1. It is note that T_1 and T_2 can be determined from S_v, and only T_2 (T_1) can be computed from S_a (S_d) owing to the shape of response spectrum. In Figure 1(a), natural periods with S_a larger than PGA are the amplified part. $T_2(S_a)$ (T_2 determined from S_a) is the intersection of the dash line extended from the corresponding S_a of period 10 sec to PGA (the dash line can be regressed by least squares method). In Figure 1(b), natural periods with S_v larger than PGV are the amplified part. $T_1(S_v)$ (T_1 determined from S_v) and $T_2(S_v)$ (T_2 determined from S_v) are the intersection of the dash line extended from the corresponding S_v of period 0.01s and 10s to PGV, respectively. In Figure 1(c), natural periods with S_d larger than PGD are the amplified part. $T_1(S_d)$ (T_1 determined from S_d) is the intersection of the dash line extended from the corresponding S_d of period 0.01s to PGD.

Since the choice of the last point of the regression line (the point with period 10s is chosen in this study) influences $T_2(S_a)$ and $T_2(S_v)$ largely, $T_2(S_a)$ and $T_2(S_v)$ is not so reliable. Thus, $T_1(S_v)$ is the demarcation of SI_a and SI_v and $T_1(S_d)$ is the demarcation of SI_v and SI_d in this study. Because most of the buildings in Taiwan have 1 to 56 stories (natural period from 0.1s to 3s), the lower and upper limits of $T_1(S_v)$ and $T_1(S_d)$ are assumed to be 0.1s and 3s, respectively. Besides, since $T_1(S_v)$ and $T_1(S_d)$ belong to area and earthquake characteristics, a set of $T_1(S_v)$ and $T_1(S_d)$ can be computed from each earthquake data. The average value of $T_1(S_v)$ and $T_1(S_d)$, $\overline{T_1}(S_v)$ and $\overline{T_1}(S_v)$, computed from numerous earthquake data in the researched area can be a representative value of the two periods in the research area. $\overline{T}_1(S_v)$ and $\overline{T}_1(S_d)$ are defined as follows:

$$\overline{T}_1(S_v) = \sum_i T_1(S_v)_i / N \tag{7}$$

$$\bar{T}_1(S_d)=\sum_i T_1(S_d)_i/N \quad (8)$$

where N is the number of earthquake data the stations in the research area collected. Therefore the definition of the novel spectrum intensity proposed in this study can be rewrite as follows:

$$SI_a(\xi)=\frac{1}{\bar{T}_1(S_v)-0.1}\int_{0.1}^{\bar{T}_1(S_v)} S_a(\xi,T)dT \quad \text{(short period) acceleration controlled period} \quad (9)$$

$$SI_v(\xi)=\frac{1}{\bar{T}_1(S_d)-\bar{T}_1(S_v)}\int_{\bar{T}_1(S_v)}^{\bar{T}_1(S_d)} S_v(\xi,T)dT \quad \text{(medium period) velocity controlled period} \quad (10)$$

$$SI_d(\xi)=\frac{1}{3-\bar{T}_1(S_d)}\int_{\bar{T}_1(S_d)}^{3} S_d(\xi,T)dT \quad \text{(long period) displacement controlled period} \quad (11)$$

The advantages of this method are easy, fast, accurate, and avoiding personal subjective factor. *SI* as defined in Eqs. (9-11) can be an index for assessing earthquake damage.

Attenuation Model

Since Campbell's attenuation form [9] can reasonably predict the characteristic of ground motion attenuation from the Taiwan strong seismic network [10], the same approach was applied in this study. Campbell's form is expressed as follows

$$Y(g)=b_1e^{b_2M_L}\left[R_h+b_4e^{b_5M_L}\right]^{-b_3} \quad (12)$$

The parameter Y is the geometric average of two horizontal PGA, which is abbreviated as horizontal PGA below, M_L is local magnitude (Richter's magnitude). Since both the PGA and M_L are controlled by short period seismic waves, M_L is better than M_w (Moment magnitude), which is controlled by the amount of fault displacement, for estimating attenuation of PGA. R_h is defined by the distance from the energy source to the recording site. In this study, hypocentral distance was used as R_h for earthquakes with small source dimension, relative to source-site distance, and the shortest distance from a station to the long fault on earth surface was adopted to approximate R_h for the Chi-Chi earthquake [10].

Genetic Algorithm

Recently, computational intelligence methods have been applied to a broad range of problems. Computational intelligence methods, such as neural networks and GA, are highly adaptive methods originating from the laws of nature and biology. Unlike mathematical methods, one of the important characteristics of computational intelligence methods is their effectiveness and robustness in coping with uncertainty, insufficient information, and noise.

The method of string representation in the GA used this study, is shown in Figure 2. In this method of string representation, the value of each parameter is represented by a sub-string of *k*-bit binary integers. In a simple GA [11-12], a string is composed of sequentially connecting all the sub-strings. Figure 3 shows the typical string representations in a simple GA using binary bits (each parameter is encoded in an 8-bit binary string in Figure 4). The binary bits for the parameters are sequentially concatenated in a simple GA.

To generate the fitter string, a GA reproduces the population according to their relative fitness; the strings with higher fitness have a better chance of passing their genes to the next generation. The proportional method is used to select the members of the next generation. A pair of parents is selected by the roulette wheel method. The slots on the perimeter of the roulette wheel are assigned to the individuals in proportion to their relative fitness functions. After reproduction a one-point crossover, with the probability of p_c, is performed to evolve new offspring. In addition, to inhibit premature convergence during reproduction and crossover, mutation, with the probability of p_m, is implemented to maintain the genetic variability of the string.

Figure 4 shows the essential elements of a simple GA, which starts with a randomly generated population of individual possible solutions scattered over a pre-determined search space (the region in which the best answer is thought to lie). The relative fitness of these individuals is determined and a stochastic selection process biased towards the fitter individuals is used to select parents for mating. In mating, attributes of the parents are mixed to form offspring which may or may not be fitter than one or both of the parents. In forming offspring, occasional random mutations can occur and also have the possibility of leading to a fitter individual. The process of selection, mating and mutation is repeated over a number of generations to allow the solution to evolve towards an optimum.

5. Results and Discussion

The objective function used in this paper was defined as follows

$$\sum_{p=1}^{P} \frac{1}{\sqrt{R_{h,p}}} (\ln Y_{m,p} - \ln Y_{e,p})^2 / P \tag{13}$$

where $Y_{m,p}$ and $Y_{e,p}$ are the measured and estimated *SI* of the *p*th instance, respectively. *P* is the total number of occurrences, and $R_{h,p}$ is the hypocentral distance of the *p*th instance. The SI_a, SI_v, and SI_d are as follows:

$$SI_a(\xi) = \frac{1}{0.25 - 0.1} \int_{0.1}^{0.25} S_a(\xi, T) dT$$

$$SI_v(\xi) = \frac{1}{0.95 - 0.25} \int_{0.25}^{0.95} S_v(\xi, T) dT$$

$$SI_d(\xi) = \frac{1}{3 - 0.95} \int_{0.95}^{3} S_d(\xi, T) dT$$

Figure 5 shows the attenuations of SI_a, SI_v, and SI_d.

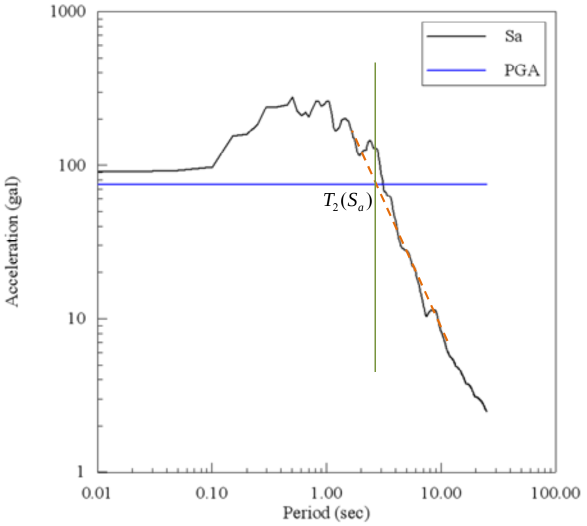
6. Conclusion

This paper developed a novel three-parameter spectrum intensity system. The three period ranges of the proposed spectrum intensity are determined by the earthquake records the stations in a certain area collected since the adequate period range of the *SI* belongs to area and earthquake characteristics. We used the attenuation models of Campbell (1981) to analyze the spectrum intensity attenuation relationships for southwestern Taiwan. Overall our results show that a useful *SI* attenuation model in southwest Taiwan deduced by the GA is

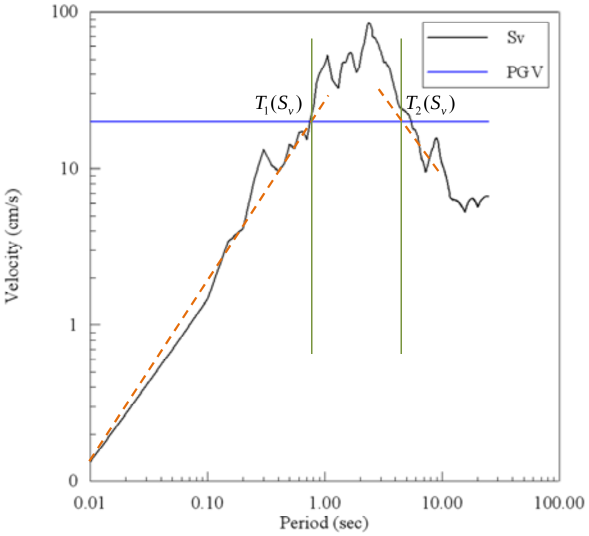
$$SI_a = 12.36e^{1.13M}(R + 3.77e^{0.01M})^{-1.19}$$

$$SI_v = 7.23e^{2.82M}(R + 7.22e^{-0.51M})^{-3.25}$$

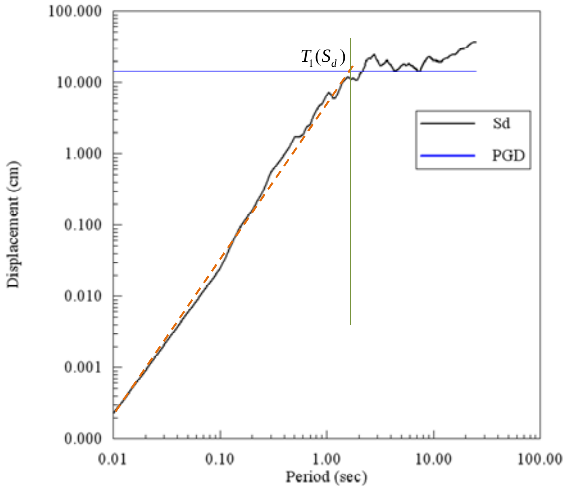
$$SI_d = 10.66e^{7.65M}(R + 4.51e^{-0.82M})^{-7.41}$$



(a)



(b)



(c)

Figure 1. A diagram of determination of cut-off periods (a) S_a (b) S_v (c) S_d

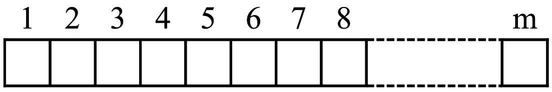


Figure 2. String representation in simple GA

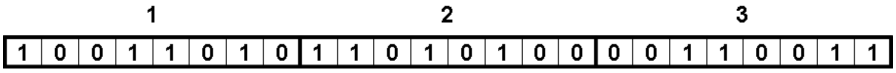


Figure 3. Example of string representation scheme in simple GA

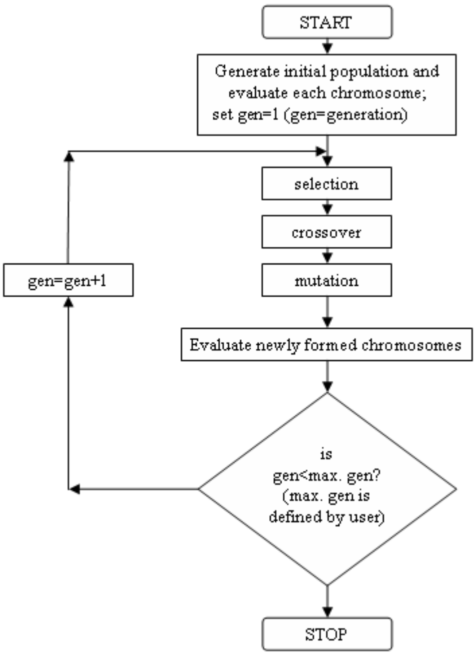
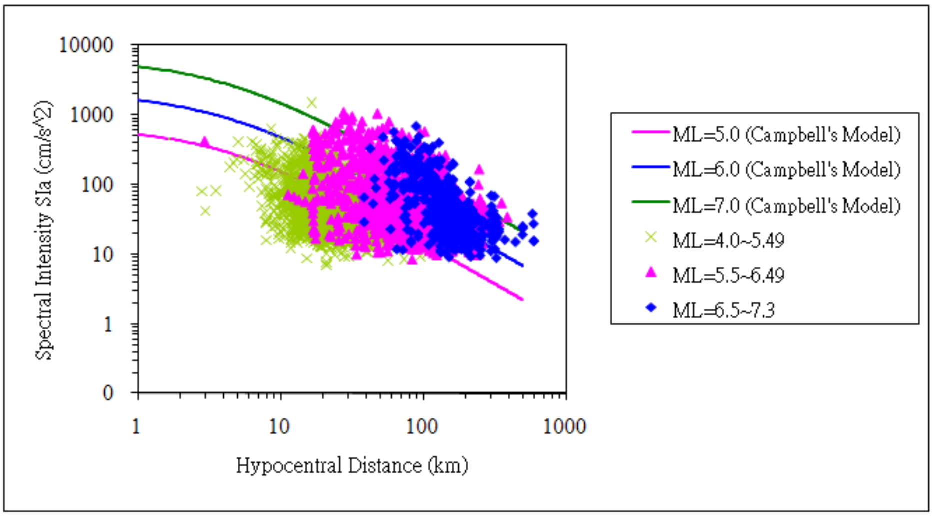
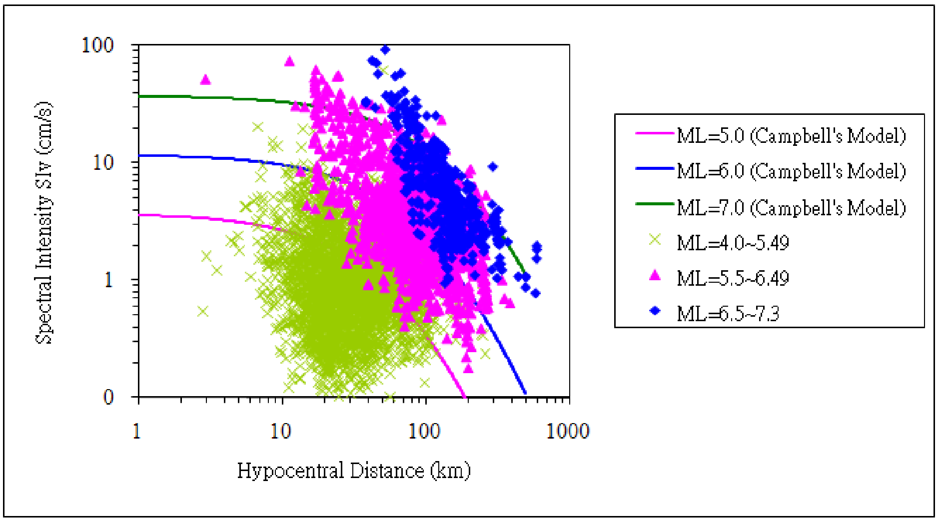


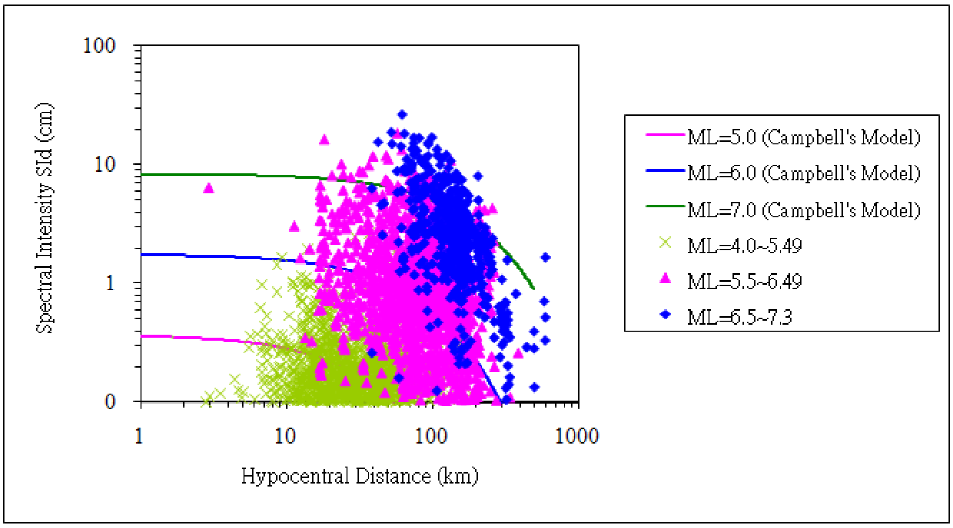
Figure 4. Elements of simple GA



(a)



(b)



(c)

Figure 5. The comparison of the earthquake data with the predicted attenuation form of (a) SI_a (b) SI_v (c) SI_d

References

1. Housner GW. Spectrum intensity of strong-motion earthquakes. In: *Proceedings of symposium on earthquakes and blast effects on structures*. EERI, UCLA; 1952.
2. Hidalgo P, Clough RW. Earthquake simulator study of a reinforced concrete frame. *Report UCB/EERC-74/13*, Berkeley, CA: EERC, University of California; 1974.
3. Matsumura K. On the intensity measure of strong motions related to structural failures. In: *Proceeding of 10th WCEE*, vol I; 1992. 375-380.
4. Nau JM, Hall WJ. Scaling methods for earthquake response spectra. *Journal of Structural Engineering*, 1984; 110(7): 1533-1548.
5. Martinez-Rueda JE. Scaling procedure for natural accelerograms based on a system of spectrum intensity scales. *Earthquake Spectra*. 1998; 14(1): 135-152.
6. Jean WY, Chang YW, Wen KL, Loh CH. Site effect analysis of Taipei Basin. *Structural Engineering* 2002; 17(3):3-17 [in Chinese].
7. Ueong YS. A study on feasibility of SI for identification of earthquake damages in Taiwan. *Soil Dynamics and Earthquake Engineering* 2009; 29:185-193
8. Liu KS, Shin TC, Tsai YB. A free-field strong motion network in Taiwan: TSMIP. *Terrestrial Atmospheric and Oceanic Sciences* 1999; **10**(2): 377–96.
9. Campbell KW. Near-source attenuation of peak horizontal acceleration. *Bull. Seism. Soc. Am.* 1981; 71:2039-2070.
10. Jean WY, Chang YW, Wen KL, Loh C H. Early estimation of seismic hazard for strong earthquakes in Taiwan. *Natural Hazards* 2006; 37:39-53.
11. Goldberg DE. *Genetic algorithms in search, optimization, and machine learning*, Addison-Wesley 1989.
12. Holland JH. *Adaptation in nature and artificial systems*, University of Michigan 1975.

出席國際學術會議心得報告

計畫編號	NSC 98-2119-M-041-001-
計畫名稱	台灣地區譜震度衰減律的研究(II)
出國人員姓名 服務機關及職稱	葉永田；嘉南藥理科技大學產業安全衛生與防災研究所特聘教授
會議時間地點	2010 年 5 月 2 日到 5 月 7 日於奧地利維也納
會議名稱	2010 年「歐洲地球科學聯盟會議」(European Geosciences Union General Assembly 2010)
發表論文題目	A Study on the Relationship between Disaster and Spectral Intensity

一、參加會議經過

歐洲地球科學聯盟會議，係由歐洲地科聯盟（European Geosciences Union，簡稱EGU）每年舉辦一次，是歐洲地區與AGU合作推動之會議，為歐洲地區地球科學學術研究最重要、規模最大的國際學術盛會。本屆會議在594個分組共收錄約4431篇口頭報告及9370篇壁報論文。與會人員來自94個國家，共有10463位科學家參與，台灣也有81位參與此會議，以人數而言占第27位，顯示此會議已受國內外許多人之重視。

本次會議於五月二日至五月七日舉行，舉辦地點在奧地利維也納之 Austria Center Vienna (ACV)會議中心，本人於五月一日到達維也納，二日完成報到手續。本會議屬於國際性研討會，會議主題廣泛，且議程安排的相當緊湊，因此本人僅能就相關的研究課題以及較為感興趣之演講場次進行聆聽，包括 Natural Hazards (NH) 分組之 Earthquake Hazards, Landslide Hazards；Seismology (SM) 分組之 General Seismology，Earthquake Sources & Faults， Early Warning， Prediction & Hazards。另外，利用一些空檔時間至 Poster 區及展覽區看看；此次共有 70 個展示攤位，分在兩個樓層，可算是規模不小之展覽。

本次會議本人於 5 月 5 日於 Seismology (SM1.1)分組以壁報方式發表論文，題目為「A Study on the Relationship between Disaster and Spectral Intensity」，主要報告本人所執行國科會計畫之研究成果。

二、與會心得

歐洲地球科學聯盟會議約於每年4至5月舉辦，本人第二次參與 (第一次是很多年前在法國Nice)。兩次的感覺都很不錯，可認識不同地區的同行並互相討論相關研究事項；且由於內容廣泛，包含地球科學各學門，也是台灣目前參與人數較多之國際會議，國內地科界同仁亦可趁此時碰面交誼，可惜本次會議在強地動方面之議題較少，不過卻讓我有時間參與地震預警與地震防災之議程。

無衍生研發成果推廣資料

98 年度專題研究計畫研究成果彙整表

計畫主持人：葉永田　**計畫編號：**98-2119-M-041-001-

計畫名稱：台灣地區譜震度衰減律的研究(II)

成果項目			量化			單位	備註（質化說明：如數個計畫共同成果、成果列為該期刊之封面故事...等）
			實際已達成數（被接受或已發表）	預期總達成數(含實際已達成數)	本計畫實際貢獻百分比		
國內	論文著作	期刊論文	0	0	100%	篇	
		研究報告/技術報告	1	1	100%		
		研討會論文	1	1	100%		
		專書	0	0	100%		
	專利	申請中件數	0	0	100%	件	
		已獲得件數	0	0	100%		
	技術移轉	件數	0	0	100%	件	
		權利金	0	0	100%	千元	
	參與計畫人力（本國籍）	碩士生	1	2	100%	人次	
		博士生	0	0	100%		
		博士後研究員	0	0	100%		
		專任助理	1	1	100%		
國外	論文著作	期刊論文	0	0	100%	篇	
		研究報告/技術報告	0	0	100%		
		研討會論文	1	1	100%		
		專書	0	0	100%	章/本	
	專利	申請中件數	0	0	100%	件	
		已獲得件數	0	0	100%		
	技術移轉	件數	0	0	100%	件	
		權利金	0	0	100%	千元	
	參與計畫人力（外國籍）	碩士生	0	0	100%	人次	
		博士生	0	0	100%		
		博士後研究員	0	0	100%		
		專任助理	0	0	100%		

其他成果 (無法以量化表達之成果如辦理學術活動、獲得獎項、重要國際合作、研究成果國際影響力及其他協助產業技術發展之具體效益事項等，請以文字敘述填列。)	無

🟥	成果項目	量化	名稱或內容性質簡述
科教處計畫加填項目	測驗工具(含質性與量性)	0	
	課程/模組	0	
	電腦及網路系統或工具	0	
	教材	0	
	舉辦之活動/競賽	0	
	研討會/工作坊	0	
	電子報、網站	0	
	計畫成果推廣之參與（閱聽）人數	0	

國科會補助專題研究計畫成果報告自評表

請就研究內容與原計畫相符程度、達成預期目標情況、研究成果之學術或應用價值（簡要敘述成果所代表之意義、價值、影響或進一步發展之可能性）、是否適合在學術期刊發表或申請專利、主要發現或其他有關價值等，作一綜合評估。

1. 請就研究內容與原計畫相符程度、達成預期目標情況作一綜合評估

■達成目標

□未達成目標（請說明，以 100 字為限）

　　□實驗失敗

　　□因故實驗中斷

　　□其他原因

說明：

2. 研究成果在學術期刊發表或申請專利等情形：

論文：□已發表 □未發表之文稿 ■撰寫中 □無

專利：□已獲得 □申請中 ■無

技轉：□已技轉 □洽談中 ■無

其他：（以 100 字為限）

3. 請依學術成就、技術創新、社會影響等方面，評估研究成果之學術或應用價值（簡要敘述成果所代表之意義、價值、影響或進一步發展之可能性）（以 500 字為限）

已具初步工程應用價值